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Understanding challenges to the adoption of low global warming potential refrigerants in an emerging economy

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Abstract :

The international mandate for regulating the usage of harmful refrigerants worldwide can be addressed by encouraging the use of the low global warming potential (GWP) refrigerants but the low- and medium-income countries face a lot of challenges for its adoption. In this study, the aim is to identify the factors that influence the adoption and explore their relationship. A mixed-method approach is used in this study to explore the factors that influence the adoption. In the first phase, a qualitative study was done using the TOE framework to assess the major challenges of adoption. The empirical findings provide direction for decision-makers to formulate policies to ensure the transition towards low GWP refrigerants. Likewise, different stakeholders in the refrigeration and air conditioning (RAC) sector can gain from this study by better managing the issues found in the study. This work is one of the first to examine the problem of low GWP refrigerant adoption in an emerging economy context using mixed research methods.

1.Introduction

The rapid deterioration of climate globally has led to rising temperatures and related concerns among different stakeholders. The various governments though late to react have imposed regulations to save the environment. One such regulation is related to the usage of refrigerants as it has been associated with the depletion of the ozone layer and rising temperatures (Cardoso et al., 2017). The use of synthetic refrigerants started in the 20th century because of their improved performance. The most popular of such refrigerants were chlorofluorocarbons (CFCs), which are responsible for ozone depletion and were finally banned in the 1987 Montreal Protocol (Velders et al., 2007). This limited the production and consumption of CFCs to save the environment (Bolaji et al., 2014). This gave rise to the use of hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) as alternatives to CFCs, though these were also found to be harmful and a potential threat to ozone depletion. The problem was addressed in the Kyoto Protocol in 1997, HCFCs usage was planned to be phased out by 2020–2030 and HFCs by 2040 (Abas et al., 2018). This also addresses the seventeen goals of sustainable development by the United Nations, especially the seventh clause of *affordable and clean energy*, the eleventh clause of *sustainable cities and communities,* and the twelfth clause of *responsible consumption and production.*

Global warming potential (GWP) is defined as the heat entrapped because of greenhouse gases in a specific period. IPCC's 2001 third assessment report contains the calculation of GWP (Houghton et al., 2001). The refrigeration industry is compelled to reduce the usage of high-GWP HFCs. It is imperative to introduce low GWP refrigerants with zero ozone-depleting potential (ODP). The ultimate target is to reduce 146 billion tonnes of carbon dioxide equivalent by 2050 (Velders et al.,2007, 2009). The reaction has been different by different countries regarding the target set for phasing out the polluting refrigerants. The European Union has taken the lead role in limiting polluting refrigerants by putting

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up adequate regulations as per the Kigali amendments. There is a need for adequate action by emerging economies as well which unfortunately lacks attention and drive by the respective governments and the organizations. Multiple challenges are there for the adoption of low GWP refrigerants, but academic research on the area is limited.

The above discussion provides an opportunity to assess and capture industry perspectives about the challenges for the usage and acceptance of low GWP refrigerants. The discussion above provides a platform to identify and capture industry perspectives about the challenges faced for usage and acceptance of low GWP refrigerants by the refrigeration and air conditioning (RAC) sector and their channel partners in the context of India. Here India is considered as representative of low- and middle-income countries. The research questions are:

What technological, organizational, and environmental factors influence the organizational adoption of low GWP refrigerants for the Indian RAC sector?

The present study hovers around the following research objectives:

To assess and capture the *technological, organizational, and environmental factors* that influence the acceptance and usage of low GWP refrigerants.

To construct a TOE-based framework comprising the identified factors related to the adoption.

To understand the causal relationships among the factors that significantly influence the adoption decision within the TOE framework.

In the present paper, the key elements that influence the acceptance and usage of low GWP refrigerants in the Indian RAC sector are explored using the mixed research method. This combines both qualitative and quantitative research exploiting the advantages of both. The study in the area is limited and mainly uses a single method of research. Therefore, the present work uses a mixed method of research where both quantitative and qualitative methods are applied to realize the topic of research (Venkatesh et. al. 2013). To describe the complex behavior of addressing the low GWP refrigerant adoption issue, a mixed-method approach can be more appropriate than the single-method approach. This may advance the research avenue by explaining the strategies in the adoption process. The detailed guidelines for the mixed method approach are taken from the work of Golicic and Davis (2012) and Venkatesh et al. (2013).

This study has two parts. In the first portion, qualitative research is used, dealing with the perception of `industry users regarding refrigerant usage from different perspectives with theoretical underpinning. This was done through detailed interviews of executives from the Indian RAC sector. In the second part of the study, the questionnaire-based survey and analysis of data are done to examine the relationship between the factors that influence the adoption of low GWP refrigerants by the RAC sector in India.

2. Literature review

As discussed in the introduction, the academic literature has been relatively silent on the issue of refrigeration adoption, and very few studies are there discussing the related challenges. Some notable studies are there from a developed country perspective like the study by Purvis et al. (2001) and Drake et al. (2004), who explored the refrigeration industry in the United Kingdom. They studied the reasons limiting the use of environmentally friendly refrigerants. A similar study was done by Dreepaul and Elahee (2018) in Mauritius, where they explored the issue of acceptance and usage of safer

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refrigerants. Similarly, Sooben et al. (2019) in their study in the supermarket sector tried to address the adoption of CO_2 towards a sustainable environment.

2.1. Challenges to the acceptance and usage of low GWP refrigerants

The identified barriers are depicted in Table 1 with brief descriptions. Considering the literature review and the identified elements thereon, it was observed that apart from technological complexity, the environmental and organizational aspects also play a key role in low GWP adoption. Drawing upon the TOE theoretical lens (Bai and Sarkis, 2020; Lai et al., 2018; Tornatzky et al., 1990; Wong et al., 2019) for the identification of various barriers, the elements are categorized into technological barriers (T), organizational barriers (O), and environmental barriers (E). The former two barriers, i.e., T and O, are endogenous while the latter barrier E is exogenous to the organizations.

It can be observed from the literature that very few studies have been done from the perspective of low- & and middle-income countries. This provides a ground to explore the problem of low GWP refrigerant adoption in the Indian context as a representative case of low and middle-income countries and understand the association among the barriers from a theoretical lens.

3. Research Methodology

The study uses a sequential approach used by Venkatesh et al. (2013) where the data analysis is performed phase-wise. The first phase of the study uses a qualitative approach and in the second phase quantitative approach is adopted. Inspired by the mixed method strategy suggested by Venkatesh et al. (2013), the factors related to the research goals are extracted from the interviews conducted in the first phase. This was followed by a quantitative study to establish the theoretical framework developed out of the first phase.

The first phase started with detailed personal interviews done with the managers from the RAC sector in India, (details provided in the next section). The literature review output was compared with the output of the literature survey to generate a framework for the study. The purpose of the framework was to provide a structure that can guide future related decisions. Building on existing work and using data from empirical studies, this work uses well-established theory to develop the framework. There are intrinsic challenges, but the present research primarily focuses on the elements that contributes to complexities that can be assessed during the adoption phase. The purpose of the stated approach was to use the framework in the early adoption phase.

Academia has an important role to play in providing an unbiased foundation based on theory to promote further research (Simangunsong et al., 2012). The aim is to integrate the theory and empirical data for a better explanation of a complex phenomenon (Hitt et al., 2002; Soltani et al., 2014). Thus, the RAC sector can take the help of theory-based research to find solutions to relatively new technology like low GWP refrigerant and its adoption issues. Many researchers have widely used the technology-organization-environment (TOE) framework for studying the adoption of new technologies. Pan and Jang (2008) studied the adoption of enterprise resource planning software in the communication industry using the TOE framework. The adoption of an e-procurement system was studied using the TOE framework by Teo, Lin, and Lai (2009). Lin (2014) used TOE to study the adoption of an electronic supply chain management system. The present study takes inspiration from these works to study the complexities in the adoption of low GWP refrigerants in the Indian context.

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4. Qualitative design and data analysis

In this study, experts from four AC manufacturing firms in India participated. These are some of the major AC manufacturing firms in the country both from Indian and foreign origin having a substantial share in the domestic market. The foreign firms operating in India, have their operations in other parts of the world and operating under different conditions. This gave a different dimension to the study. In India, there is a general lack of guidelines for phasing out HFCs compared to developed countries (Purohit et al., 2016). This affects the choice of refrigerants in the RAC sector. The participants of the present study are the middle-level managers of the firms having the requisite technical and commercial knowledge. The same practice was done by Purvis et al. (2001) and Drake et al. (2004), who believed that the middle-level managers were the proper respondents. The study's objective was thoroughly explained to the participants. From each of the four firms, in total seventeen experts who showed keen interest were chosen for the study. The expert's details are given in Table 2. A replication logic as suggested by Yin (2002) was used for the selection. The logic was to extract the maximum information from a small sample (Flyvbjerg, 2006). Following the protocol, seventeen semi-structured interviews were conducted, and the transcript was created. A general interview protocol as mentioned in Appendix A was followed. The questions asked were open-ended and related to the elements that contributed to the adoption.

4.1 Elements of case study

The transcripts were thoroughly studied to shortlist the contributing elements. In the matrix created with the number of interviews in the column, care was taken for the confidentiality of the results. Each interview results were managed independently. The number of new elements added started decreasing considerably after a few interviews. After the 10th interview, no new elements were added indicating saturation in data collection. After the interviews, the information was informally collected from the organizations regarding their prior technology implementation.

The contributing elements from the perspective of practice were collected and confirmed with the literature elements. A total of 21 elements from the case studies are shown in Table 3, contributing to complexities involved in low GWP refrigerant adoption. They are presented based on several occurrences from the interviews. The interviewees also confirmed almost all the elements found in the literature. Different aspects of refrigerant adoption were reflected in all the cases, representing support for the aspects. The aspects were summarized in terms of "what", "who" and "how" as different clusters. "What was in terms of content", "who" in terms of the person/group involved, and "how" in terms of organizing the process? The "what" aspects were translated to the technology dimension of the adoption. The "who" aspects were

related to the environmental dimension of the adoption and the "how" aspects were translated to the organization dimension of the adoption. Thus, the elements explaining the "what", "how" and "who" are the key elements contributing to adoption. It is interesting to note that some elements do overlap in different dimensions.

4.2 The TOE framework

Taking a clue from the outcome of the literature review and data obtained based on the case studies and combining them, the elements were placed into technological, organizational, and environmental categories, called the TOE framework. The technological, organizational, and environmental elements contributing to adoption are included in the framework. It was proposed to grasp the relevant elements to be assigned to different categories. To develop a framework of adoption, the element lists

from literature and cases are combined. To ensure the richness of the framework and avoid adding unnecessary elements, the following steps were taken (Marian,2011).:

The element should be there in both literature and case

The element should be there in at least two independent literature source

The element should be there in at least three interviews from three cases

The elements related to the various complexities involved were mapped with the TOE framework. The technical and organizational complexity were explicitly included as the main category. The elements belonging to the technological category were found to have a structural nature like the technological maturity of technology, scalability issues, interoperability issues, usability, etc. In the organizational category, some elements like competence and technology awareness; lack of top management commitment, etc. are considered structural in nature. The multi-objectivity of different stakeholders like government policies, legal, and regulatory frameworks are captured in the environment category. The environment category contains many softer aspects like interfaces between various parties, trust, and availability of resources.

The framework of technological, organizational, and environmental aspects called the TOE framework included the cluster of relevant elements. On a lower level, the subcategories were formed by further grouping of the elements (Table 4). The subcategories contained the most relevant criteria obtained from the literature. In this case, four criteria each were obtained for the T, O, and E categories providing a broader view of the adoption complexity. Table 5 represents the TOE framework. It consists of 10 T elements, 11 O elements, and 18 E elements. The origin of the elements is from literature, case studies, or both and indicated by L, C, and B respectively. Most of the elements were mentioned in both the literature as well as empirical study (6 out of 10, 8 out of 11, and 12 out of 18 for the T, O, and E categories respectively). This indicated support from theoretical as well as practical aspects. In the E category, few elements were from the case study only. This may be attributed to the fact that the related environmental aspects were specific to the location and nature of the case companies. The TOE framework developed having three levels (categories, subcategories, and elements) considered the different levels of aggregation. The framework was helpful to assess the challenges of new refrigerant adoption which is often subjective in nature. There are differences in experience and understanding of the people regarding the challenges involved in the adoption process. At this stage the purpose was to assess the adoption process and the related complexity involved. The framework developed achieves the purpose of identification of adoption complexities which can help to better manage the implementation process.

Table 4: Subcategories of TOE

Technological	***Organizational***	***Environment***
Infrastructure	***Organizational resources***	***Government regulation***
Complexity	***Organizational innovativeness***	***Customer***
Capability	***Internal stakeholder***	***Competitor***
Risk	***Organizational size***	***Location***

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Table 5: TOE Framework

TOE	Sub Category	Source (Literaure/ Case/Both)	Elements defined	Explanation
T	Infrastructure	B	Internal infrastructure	Is the infrastructure adequate to suit implementation ?
T	Infrastructure	B	Compatibility	Is there compatibility with other party in the production chain?
T	Capability	B	Technology	Does the organization has the requisite competence to develop the new refrigerant or adapt it to the existing system?
T	Capability	B	Human Resources	Are there strong and dedicated professional team and proper system of training of employees ?
T	Capability	L	Human Resources	Are the experts and managers capable of increasing staff confidence in technology adoption?
T	Complexity	L	Maturity	How mature is the technology?
T	Complexity	B	Implementation	Is the development and implenetation of new refrigerants a difficult process?
T	Complexity	B	System design	Will there be an increase in system design complexity for low GWP refrigerants use ?
T	Risk	L	Safety	Is the technology safe and secure in terms of production and usage?
T	Risk	C	Facility	Can the existing production facility be adapted safely for new refrigerant production?

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O	*Organizational innovativensss*	*B*	*Orgaization Strategy*	*What is the perception of new technology as a key for achieving the company's vision and strategic goals?*
O	*Organizational innovativensss*	*B*	*Adoption Strategy*	*Is there a clear plan for adoption in the organization?*
O	*Organizational innovativensss*	*B*	*Top Management*	*Is there support for adoption by CEO and top management ?*
O	*Organizational innovativensss*	*L*	*Culture*	*Is there a culture to embrace new technology?*
O	*Organizational resources*	*B*	*Financial resources*	*Is there sufficient budget for the implementation at the required/agreed level ?*
O	*Organizational resources*	*B*	*Cost saving*	*Will there be significant reduction in cost, thus saving resources ?*
O	*Internal stakeholder*	*B*	*Organisation structure*	*Will the technology lead to improvement of internal confidence in the organization?*
O	*Internal stakeholder*	*L*	*Knowledge management*	*How to ensure management of knowledge and improve awareness of the new technology?*
O	*Internal stakeholder*	*B*	*Employee Motivation*	*How to involve operational employees at all stages of implementation ?*
O	*Organisation Size*	*C*	*Organisation size*	*What is the influence of organization size in the technology implementation?*

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O	*Organisation Size*	*B*	*Expert team*	*What is the influence of size of experts team in the technology implementation?*
E	*Customer*	*B*	*Industry Adoption*	*What is the level of acceptance among the organisation's partners in a B2B environment ?*
E	*Customer*	*B*	*Improvement in performance*	*How can the the technology help improve the performance of the product?*
E	*Customer*	*C*	*Price*	*What is the level of acceptance of the technology among the customers in terms of pricing?*
E	*Supplier*	*B*	*Cooperation*	*How to ensure adequate support from the local chemical industries and embibe trust & confidence with the new technology?*
E	*Supplier*	*B*	*Contractual agreement*	*How to develop a contract with suppliers based on mutually agreed terms and to share rewards/risks ?*
E	*Supplier*	*B*	*Assistance*	*How to bring confidence by assisting the suppliers with technical help?*
E	*Supplier*	*B*	*Ecosystem*	*How to develop an ecosystem of trained service and maintenance contractors*
E	*Competitor*	*C*	*Industry Adoption*	*What is the level of awareness among companies of the industry?*
E	*Competitor*	*B*	*Adoption challenges*	*What are the difficulties in dealing with business partners not using the low GWP refrigerants?*
E	*Competitor*	*B*	*Industry requirement*	*Is it a strategic necessity to introduce the refrigerant to compete in the marketplace*

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E	***Location***	***C***	***Support structure***	***What is the level of experience/expertise/support in the country using the new refrigerant?***
E	***Location***	***L***	***Industry strategy***	***What is the level of strategy on low GWP refrigerants adoption in the country ?***
E	***Location***	***B***	***Social and cultural beliefs***	***Is there inherent trust and understanding among local parties to ensure smooth implementation ?***
E	***Location***	***C***	***Social beliefs***	***Is there inherent resistence to change prevailing in the organization ecosystem ?***
E	***Government regulation***	***B***	***Jurisdictional Issues***	***Is there a legal framework, including the relevant privacy laws, consumer laws, licencing, security regulations, etc.***
E	***Government regulation***	***B***	***Jurisdictional Issues***	***Is there adequate steps by Government to enforce regulations uniformly?***
E	***Government regulation***	***C***	***Government support***	***Does the government accepts and encourages low GWP refrigerants ?***
E	***Government regulation***	***B***	***Government support***	***Does the government taking sufficient steps to curb the use of low quality refrigerants by unbranded firms?***

L = based on literature data, C = based on empirical data, B = based on both literature and empirical data.

5 Discussion

This work is one of the first to examine the issue of low GWP refrigerants in low and middle-income country context using mixed research methods. The in-depth study in phase I highlighted many of the important challenges for adoption. In this work, the effort was to establish a consensus between the findings obtained from qualitative and quantitative work (Venkatesh et al., 2013). In phase I, the

qualitative study reveals the importance of government support as one of the most important factors for adoption. This further corroborated the importance of the role of government in comparison to other factors to adopt low GWP refrigerants. The findings further highlight that to achieve the sustainable goals set by the United Nations, a lot of responsibility lies with the local governments.

The same thing was echoed in qualitative studies, where the effectiveness of the new refrigerant was discussed both in the case as well as literature. The organizational capability in the development and usage of new refrigerants and its supply chain was affirmed by the experts as well as a literature review. The organizational readiness for the adoption and the technical capability of its people, suppliers, and contractors were highlighted. Customer awareness was realized to be important in the qualitative method.

6 Research Implications and Limitations

The present study offers some significant contributions. Theoretically, the research offers a unique approach to the low GWP adoption in the emerging economy context by integrating previous research and empirical case research into a TOE framework. The significance of the study lies not only in offering a theoretical base for understanding and assessing the factors related to adoption but also exploring the cause-and-effect relationship among them. On practical side, this study offers firms a framework and an overall view of the factors to be considered for the transition to the new refrigerant. It is expected that the outcome will ease the firm's effort to adopt new refrigerants.

The study reveals the importance of the role of government in ensuring transition towards low GWP refrigerants. It is important to formulate laws and enforce their implementation. Also, the government should provide adequate support so that the technology becomes accessible to all manufacturers including the SMEs in the RAC sector. A proper ecosystem developed by the local government will encourage the manufacturers to invest in the related technology. This may start with incentivizing the manufacturers to invest in their R&D and upgradation of skills through training. There can be a standard certification program for technicians engaged in manufacturing and maintenance. The other role of the government lies in monitoring the usage of proper refrigerants. Organizations adopting low GWP refrigerants should be incentivized accordingly. A special awareness program for the customer should be initiated to sensitize them to cleaner and sustainable options. The study also provides direction to the RAC sector for planning for the future. The barriers discussed through literature and case studies can be utilized by the organizations for planning and prioritizing the actions. The present work throws an opportunity for the researchers to study the area of low GWP refrigerant adoption from different theoretical lenses. The study can be replicated for other countries' context to get insights about the adoption problem.

The study does have certain limitations. It deals with limited barriers in the Indian context which may vary for other countries. Further, the study uses a small sample size and future studies may concentrate on a larger sample size.

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Table 1: Barriers identified from the literature

Barrier Category	Description	Reference
Technological	The inflammable and toxic nature of the low GWP refrigerants making them unsafe	Purvis et al. (2001), Heubes et al. (2012), Colbourne (2010), Bolaji and Huan (2013), Lamb (2016), Cardoso et al. (2017), Abas et al. (2018), Feng et al. (2019)
	Lack of facilities for the research and development of low GWP refrigerants	Heubes et al. (2012), Park (2019)
	Limited applicability of the low GWP refrigerants	Lamb (2016), Cardoso et al. (2017), Ciconkov (2018), Abas et al. (2018)
	System design complexity often increases with the use of low GWP refrigerants as it requires a change in the design for the exiting products	Bolaji and Huan (2013), Cardoso et al. (2017), Abas et al. (2018)
	Technology required for the use of the low GWP refrigerants often demands high investment	Dreepaul and Elahee (2018), Sooben et al. (2019), Maija et al. (2014)
	Limited technical capabilities of the local service and maintenance contractors	Purvis et al. (2001), Heubes et al. (2012), Ciconkov (2018)

	Lack of qualified technicians to handle low GWP refrigerants	Colbourne (2010),Heubes et al. (2012), Dreepaul (2017), Dreepaul and Elahee (2018), Ciconkov (2018), Sooben et al. (2019)
Organizational	Low GWP refrigerants alternative may not be aligned with the commercial interests of the firm	Purvis et al. (2001), Drake et al. (2004), Colbourne (2010), Minetto et al. (2018)
	High cost of the low GWP refrigerants decreasing the acceptance in the price-sensitive market in developing countries	Colbourne (2010), Heubes et al. (2012), Bolaji and Huan (2013), Lamb (2016), Cardoso et al. (2017), Abas et al. (2018)
	Firm's limited technical and financial capabilities in using low GWP refrigerants	Heubes et al. (2012), Colbourne (2010), Luthra et al. (2015), Sooben et al. (2019), Park (2019),
Environmental	Industry perception regarding the adoption of the low GWP refrigerants	Colbourne (2010), Browne et al. (2012), Chan et al. (2018)
	The limited technical capability of the local suppliers	Purvis et al. (2001), Heubes et al. (2012), Colbourne (2010), Sooben et al. (2019)
	Dependence on the chemical industry for the development of low GWP refrigerants	Purvis et al. (2001), Drake et al. (2004), Antunes and Bandarra (2016)
	The presence of a conducive system by government to reward the adoption of low GWP refrigerants	Steenberghen and Lopez (2008), Suzuki (2015), Chan et al. (2018), Ciconkov (2018), Sooben et al. (2019)
	Government's intention and efficiency to enforce regulations uniformly	Suzuki (2015)
	Ambiguity in regulations defined by the government	Colbourne (2010), Minetto et al. (2018)
	High dependency on import for low GWP refrigerants	Sanguri et al. (2021)
	Customers price sensitivity	Luthra et al. (2015)
	Low customer awareness regarding the environmental effects of the existing refrigerants	Colbourne (2010), Heubes et al. (2012), Luthra et al. (2015), Park (2019)

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Table 2: Details of the profile of the industry experts

Company origin	**Industry Experience**				**Total**
	5-10 years	**10-15 years**	**15-20 years**	**> 20 years**	
Indian I	2	1	1	1	5
Indian II	2	2	1	1	6
S. Korean I	1	1	1	0	3
American	1	1	1	0	3
Grand Total	**6**	**5**	**4**	**2**	**17**

Table 3 : Elements contributing to adoption challenges based on case study

Elements defined	No. of cases the element appeared	No. of interviews the element appeared
Effectiveness of new refrigerant	4	15
Safety concern	4	15
Government support	4	15
Technical Capability	4	15
Technical Complexity	4	14
Organization Strategy	4	14
Customer awareness	4	13
Commercial Interest of firm	4	12
Financial resources	3	12
Cost	3	11
Expert team availability	3	11
Customer acceptance	3	11
Top Management support	3	10
Industry wide Adoption	3	10
Local Industry readiness	3	10

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Jurisdictional Issues	3	10
Industry requirement	3	10
Industry strategy	2	9
Human Resources of the firm	2	9
Resistance to change	2	8
Support structure of the firm	2	7
Social beliefs and concerns	2	7

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